

# ACHIEVING MASS CUSTOMIZATION IN THE BOEING WIRE RESPONSIBILITY CENTER

By

MATTHEW KIRK NAPIER

Bachelor of Science in Molecular Biology  
University of Washington (1990)

Submitted to the Sloan School of Management and the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degrees of

Master of Science in Management and  
Master of Science in Civil and Environmental Engineering

In conjunction with the Leaders for Manufacturing Program  
at the Massachusetts Institute of Technology  
June, 2000

© 2000 Massachusetts Institute of Technology.  
All rights reserved.

Signature of Author \_\_\_\_\_

\_\_\_\_\_  
Sloan School of Management, MIT  
Department of Civil and Environmental Engineering, MIT  
May 5, 2000

Certified by \_\_\_\_\_

\_\_\_\_\_  
Duncan Simester, Thesis Supervisor  
Associate Professor of Management Science, MIT

Certified by \_\_\_\_\_

\_\_\_\_\_  
Kevin Otto, Thesis Supervisor  
Associate Professor of Mechanical Engineering, MIT

Certified by \_\_\_\_\_

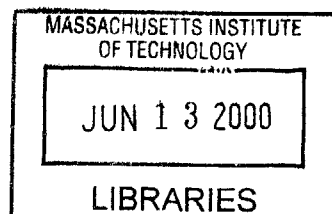
\_\_\_\_\_  
Sarah Slaughter, Thesis Reader  
Assistant Professor of Civil and Environmental Engineering, MIT

Accepted by \_\_\_\_\_

\_\_\_\_\_  
Daniele Veneziano, Chairman, Departmental Committee on Graduate Studies  
Department of Civil and Environmental Engineering, MIT

Accepted by \_\_\_\_\_

\_\_\_\_\_  
Margaret Andrews, Executive Director of the MBA Program  
Sloan School of Management, MIT



ENCLOSURE



# **ACHIEVING MASS CUSTOMIZATION IN THE BOEING WIRE RESPONSIBILITY CENTER**

By

**MATTHEW KIRK NAPIER**

Submitted to the Sloan School of Management and the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degrees of

**Master of Science in Management  
and  
Master of Science in Civil and Environmental Engineering**

## **Abstract**

Customized options are costly to produce using the current production and design methods of the Boeing Commercial Airplane Group (BCAG). The company is redesigning its engineering and manufacturing processes in order to enhance its ability to deliver customized options cost effectively. The majority of the company's continuous improvement efforts to date have centered on either its manufacturing operations or its engineering processes, and significant progress has been made in the areas of lean production and reduced flowtimes. While there is still plenty of room for improvement within each functional group of the business, there is arguably much more opportunity for improvement in the relationships between functional groups.

The thesis analyzes the potential for significant cost improvements of initiatives that focus on formalizing cross functional continuous improvement relationships between the engineering and manufacturing groups. The analysis is conducted in the form of a case study of the company's Wire Responsibility Center (WIRC), which has the distinction of handling more customization, variability and change than most other areas of the company. This high degree of variation is coupled with large volumes of product - hundreds of units per plane - to produce fertile ground for the study of process improvements between engineering and manufacturing teams.

This study shows the significant impact of the WIRC's Change, Error, and Rework (CER) Initiative on the quality and cost of its products and offers suggestions for further improvement. The thesis concludes with a discussion of how effective application of the lessons learned from this pilot project could greatly improve the profitability of The Boeing Company's Commercial Airplane Group.

### **Thesis Advisors:**

Duncan Simester

Professor of Marketing, Sloan School of Management, MIT

Kevin Otto

Professor of Mechanical Engineering, Department of Mechanical Engineering, MIT



## **Acknowledgements**

I would first like to thank The Boeing Company for their membership in the Leaders For Manufacturing Program and for sponsoring my internship. I am very fortunate to have had the opportunity to learn from such an enormously talented group of people.

Next I would like to thank the sponsors, directors, and affiliates of the Leaders For Manufacturing program. I have been blessed with opportunities to participate in some outstanding academic programs in my life but none have been nearly as rewarding. I also need to thank the Sloan Business School, the Department of Civil and Environmental Engineering, and the Massachusetts Institute of Technology and for their significant roles in the LFM experience.

My corporate and academic advisors were instrumental in making the internship and thesis project the incredible learning experiences that they were. I would like to acknowledge them individually.

I would first like to thank Mike W. Morse, my corporate advisor at Boeing, for the inordinate amount of time he spent making my internship experience so highly valuable. His experience, industry and company knowledge, list of contacts, patience, and political and social acumen were all made available to me and were greatly appreciated.

I am also very grateful for the opportunity to have worked with my incredibly talented academic advisors. Their patience and input have been invaluable. Thank you to Kevin Otto, Professor of Mechanical Engineering, for making my thesis infinitely better by taking the time to provide highly value-added feedback. Thanks also to Duncan Simester, Professor of Management Science in the Marketing Department, for taking the time to help me out despite also teaching four sections of Marketing this term. The efforts of Sarah Slaughter, Professor of Civil and Environmental Engineering, who took the time to provide valuable feedback despite short notice, are also greatly appreciated.

Many individuals at Boeing need to be recognized individually for their time and efforts. They are: Mike Denton, my executive sponsor, Blake Emery, Archie Cohn, Bill Greene,

Rob Reimers, and Bob Lebo from the ACPS group, Bruce Moravec, Dave Ball, Matt Gianni, Garth Windley, Ron Ericksen, Tasha Rankin, Bob Carnahan, and others from the WIRC, Steve Rolling from Customer Engineering, and Mike Mesick from 737/757 QA.

I would also like to thank all the LFM alumni at Boeing whose hospitality, time, experience, and knowledge were greatly appreciated. I would especially like to acknowledge Keith Jackson, Lindsay Anderson, Mike Carnette, Tim Copes, and Sharon Reickels for their availability and/or for greatly improving my final presentation.

I would like to thank my fellow LFM intern Oliver Weir for sharing his knowledge, contacts, and input before, during, and after our seven months at The Boeing Company.

Finally, I would like to thank my friends, family, and classmates for their guidance, patience, and friendship during this stressful process.

My fiancée, Sarah Evans, is especially appreciated for her love, companionship, understanding, and patience in support of my education and our relationship.

# Table of Contents

<b>LIST OF FIGURES</b>	<b>9</b>
<b>1 INTRODUCTION AND OVERVIEW</b>	<b>10</b>
1.1 MASS CUSTOMIZATION – DEFINITION	10
1.1.1 EXAMPLES	10
1.1.2 APPLICATION TO THE BOEING COMMERCIAL AIRPLANE GROUP (BCAG)	11
1.2 GENERAL METHODS FOR ACHIEVING MASS CUSTOMIZATION	12
1.2.1 PROJECT FOCUS – THESIS STATEMENT	13
1.2.2 CONTINUOUS IMPROVEMENT – DEFINITION	13
1.2.3 MODULARITY – DEFINITION AND EXAMPLES	14
1.3 PROJECT OVERVIEW	16
1.4 RELATED RESEARCH	17
1.5 THESIS OUTLINE	17
<b>2 PRODUCTION SIDE OF INTEGRATION TO SUPPORT MASS CUSTOMIZATION</b>	<b>18</b>
2.1 COMPANY BACKGROUND, POSITION, AND OUTLOOK	18
2.1.1 MASS CUSTOMIZATION – PROGRESS TO DATE	18
2.2 THE WIRE RESPONSIBILITY CENTER (WIRC)	19
2.2.1 THE WIRC’S POSITION IN THE AIRPLANE PRODUCTION PROCESS	20
2.3 UNIQUE ASPECTS OF THE WIRE RESPONSIBILITY CENTER	21
2.4 PROJECT FOCUS - ADVANCED DESIGN CHANGE NOTIFICATIONS (ADCN’S)	21
<b>3 DEVELOPMENT SIDE OF INTEGRATION TO SUPPORT MASS CUSTOMIZATION</b>	<b>23</b>
3.1 OVERVIEW OF WIRC DEVELOPMENT PROCESSES	23
3.2 FEEDBACK SYSTEMS/INTERFACES	26
3.3 WIRC SHOP FLOOR LAYOUT	26
3.4 THE ELECTRICAL CORRECTIVE ACTION TEAM (ECAT)	28
<b>4 ANALYSIS OF DIFFICULTIES IN INTEGRATION TO SUPPORT MASS CUSTOMIZATION</b>	<b>29</b>
4.1 PROBLEM DISCOVERY	29
4.2 THE CHANGE, ERROR, AND REWORK (CER) INITIATIVE	30
4.2.1 COST IMPACT OF ERRORS	31
4.3 THE FIRST ITERATION	32
4.3.1 INITIAL RESULTS	33
4.3.2 THE REST OF THE STORY	35

4.3.3	LESSONS LEARNED	36
4.3.4	NEXT STEPS	37
<b>5</b>	<b>SOLUTION TO THE DIFFICULTIES OF INTEGRATION TO SUPPORT MASS CUSTOMIZATION</b>	<b>39</b>
<b>5.1</b>	<b>SHORT TERM OPPORTUNITIES</b>	<b>39</b>
5.1.1	INTEGRATION OF THINKING AND DOING	39
<b>5.2</b>	<b>LONG TERM POSSIBILITIES</b>	<b>40</b>
<b>5.3</b>	<b>ENABLING MASS CUSTOMIZATION</b>	<b>41</b>
<b>6</b>	<b>CONCLUSIONS</b>	<b>43</b>
<b>6.1</b>	<b>CONTINUOUS IMPROVEMENT IN ENGINEERING</b>	<b>43</b>
<b>6.2</b>	<b>IMPACT ON BCAG'S PROFITABILITY</b>	<b>44</b>
<b>7</b>	<b>APPENDIX</b>	<b>45</b>
<b>8</b>	<b>ENDNOTES</b>	<b>46</b>



## **List of Tables**

<b>Table 1: Five Fundamental Strategies for Mass Customization</b>	<b>12</b>
<b>Table 2: Estimated Cost Savings From Reduction in WIRC ADCN's 737NG Program</b>	<b>32</b>

## **List of Figures**

<b>Figure 1: Continuous vs. Breakthrough Improvement</b>	<b>14</b>
<b>Figure 2: Six Types of Modularity for Mass Customization</b>	<b>15</b>
<b>Figure 3: Overview of Airplane Production Process</b>	<b>20</b>
<b>Figure 4: Overview of WIRC Processes</b>	<b>23</b>
<b>Figure 5: Engineering and Design Layout and Process Flow</b>	<b>25</b>
<b>Figure 6: WIRC Fabrication Shop Floor Layout</b>	<b>27</b>
<b>Figure 7: Sources of ADCN's for the 737NG</b>	<b>29</b>
<b>Figure 8: Total Number of WIRC ADCN's for the 737NG April – July 1999</b>	<b>30</b>
<b>Figure 9: Sample CER Initiative Error Type Feedback Form</b>	<b>33</b>
<b>Figure 10: Percent of Error Free Drawings</b>	<b>34</b>
<b>Figure 11: Total Number of WIRC ADCN's for the 737NG, July – Oct 1999</b>	<b>35</b>
<b>Figure 12: Sample of Improved CER Feedback Form</b>	<b>37</b>

# 1 Introduction and Overview

## 1.1 Mass Customization – Definition

It sounds so simple. Mass customization is the production and distribution of customized goods and services on a mass basis<sup>1</sup>. It is a paradox. Until recently, the terms *mass* and *customized* were considered to be mutually exclusive opposites in the manufacturing world. Modern technology is challenging this assumption and transforming the idea of mass customization from an impossible dream to a tangible and attainable competitive advantage.

As an “umbrella concept<sup>2</sup>”, mass customization covers a broad range of techniques and possibilities, depending on the industry being observed. *Mass* is a relative term, not only within a specific industry, but also between industries. There are also varying degrees of customization within and across industries. The ultimate goal of mass producing individually customized goods and services is more attainable in some industries than others. The tenets of mass customization, however, can be applied universally to achieve tremendous increases in variety without corresponding increases in cost.

### 1.1.1 Examples

Customization in the form of product proliferation is running rampant in every industry from banking to breakfast cereals. There are dozens of choices to be made during what used to be a simple task of buying toothpaste and a toothbrush. Setting up phone service and subscribing to cable television involve deciding between an ever-increasing number of options and packages<sup>3</sup>.

The computer industry is well known for its ability to offer personalized systems at little or no additional cost. Toyota is allowing customers to design their own cars, from a limited set of options, with a delivery target of five days.

Cars are a good example of a product that is relatively large, complex, and highly integrated, much like airplanes. The auto industry has not matched the level of mass customization of other industries, but companies like Toyota have achieved significant

competitive advantages by pursuing the ideal. Houses are another relatively large example. Modular housing companies in Japan and Scandinavia are mass customizing highly individualized manufactured homes that bear no resemblance to the prefabricated version sold in the United States<sup>4</sup>.

Even specialized machine makers, like Ingersoll Milling Machines in the United States, and Valmet Paper Machinery in Finland, are achieving lower costs and higher quality in their craft-produced products<sup>5</sup> by applying the principles of mass customization. Craft manufacturing is the antithesis of mass production (it is the way cars were made before Ford introduced standardized parts and the moving assembly line<sup>6</sup>). If this costly, inefficient, labor-intensive means of production can benefit from mass customization, any company with modern production methods can as well. If craft manufacturers of paper machines, which produce highly specialized products in volumes of only one or two per year, can apply the technological principles of mass customization, so too can The Boeing Company.

#### 1.1.2 Application to the Boeing Commercial Airplane Group (BCAG)

This logic also works in reverse. Industries with simpler products and shorter product life cycles like computers also gain tremendous competitive advantage through mass customization. The “DNA” of mass customization is as applicable to these “fruit fly<sup>7</sup>” products and companies as it is to larger, more complex products and companies.

The term mass customization can also be used as a communication tool for managers to explain why development and production cycle times must decrease, why hierarchies are flattening, and why the business is re-engineering its processes.

Customization is a very familiar concept to Boeing. BCAG’s products are already customized to a very large degree. For example, customers often differentiate their airplanes around interior layout, such as seating arrangements and positioning of galleys and lavatories. The problem for Boeing is the cost associated with the customization. Proper application of the mass customization strategies that are germane to Boeing’s business can have a profound effect on the company’s competitiveness and profitability.

## 1.2 General Methods for Achieving Mass Customization

In research on a variety of products, B. Joseph Pine found that there are five fundamental strategies for achieving the low cost-production of customized products<sup>8</sup>. They are listed in Table 1 along with examples from within BCAG.

**Table 1. Five Fundamental Strategies for Mass Customization**

General Method	Boeing Example
1. Customize services around standardized products and services.	1. Offer service packages with varying lease and maintenance options.
2. Create customizable products and services.	2. Design floors to accommodate interchangeable seating arrangements.
3. Provide point-of-delivery customization.	3. Mass produce generic airplane bodies and customize in a separate facility.
4. Provide quick response throughout the value chain.	4. Close relationships with suppliers, lean operations and design, continuous improvement.
5. Modularize components to customize end products and services.	5. Defined interfaces for monuments (galleys and lavs), open architecture “plug-and –play” avionics and entertainment electronics.

The relevance of these methods varies from industry to industry, depending on a myriad of factors such as product size, production volume, number of suppliers, and product complexity, among many others. As Table 1 shows, however, they are all potentially applicable to BCAG. They also represent a huge opportunity for Boeing to decrease production costs, increase customer satisfaction, and bury its competition.

As will be seen in Chapter 2, the company has made some progress in these areas. Teams have been formed to perform feasibility studies on all five of these methods to determine which of them make the most sense for Boeing to pursue and in what order they should be implemented. Point-of-delivery customization (#3), also known as “Last-Stage Customization”, may be an option for some airplane models but implementation of this strategy would be overly disruptive and costly to Boeing’s business and isn’t expected to become viable in the foreseeable future. The high degree of integrality in airplanes, which causes customization decisions to impact early steps in production (extra cargo capacity requires thicker airplane “skin”, for example), is another sizable deterrent for this strategy.

Boeing's progress in applying these customization methods will be discussed further in section 2.1.1. A brief overview is presented here. Method #1, customizing around services, is being pursued in conjunction with methods 2, 4, and 5, which deal more with the production of customized products. The company has recognized the opportunities and advantages of creating customizable products (#2), providing quick response throughout the value chain, called lean production and design (#4), and designing modularized components such as "plug-and-play" entertainment electronics (#5) that can be easily combined to create customized products. Creating customizable products and designing modularized components, however, require enormous engineering resources that cannot be spared at this time.

#### 1.2.1 Project Focus – Thesis Statement

The company has explored ways of providing quick response throughout the value chain (method #4), mostly through close relationships with suppliers and lean production initiatives. This project focuses on providing this quick response by capitalizing on continuous improvement opportunities between the engineering and manufacturing teams of BCAG. It shows how cost-effective mass customization can be achieved by formalizing cross-functional continuous improvement methodologies between engineering and manufacturing teams.

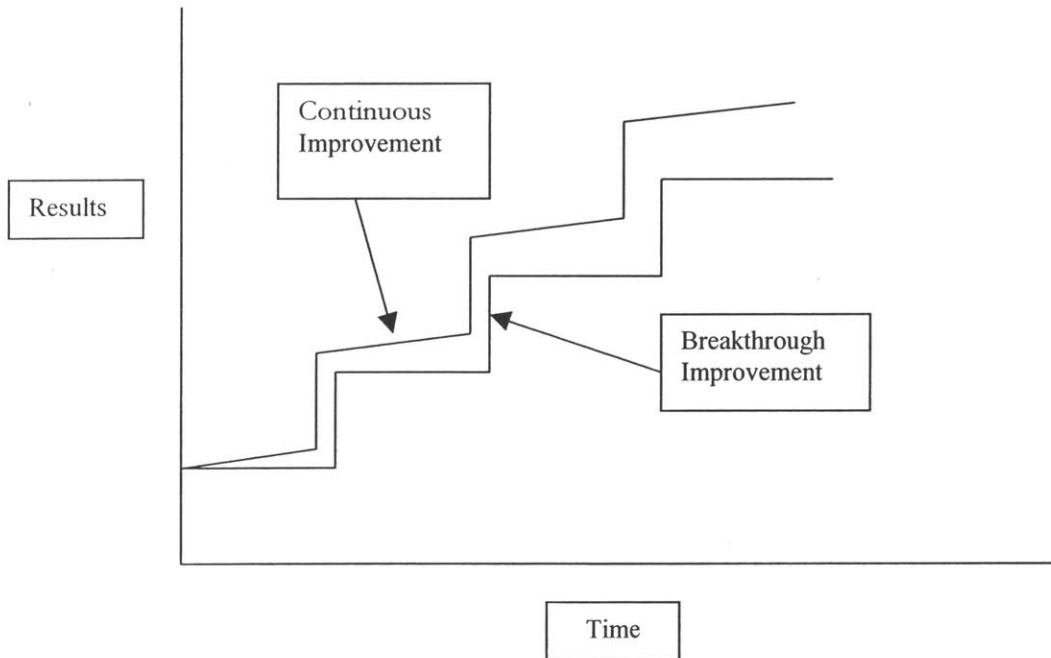
#### 1.2.2 Continuous Improvement – Definition

Continuous improvement has many meanings. For the purpose of the thesis, continuous improvement will be distinguished from "breakthrough improvements". As Figure 1 shows, continuous improvement can be thought of as refining the processes that occur in between breakthrough innovations<sup>9</sup>. As will be discussed further in Chapter 2 and Chapter 6, the company has a long and successful history of achieving breakthrough

improvements during new model introductions. New wing designs, two-person cockpits, and extended range are examples of breakthrough improvements. Defect reduction efforts such as GE's six sigma program and incremental cost improvements driven by new materials sourcing or supply chain management are examples of continuous improvement.

The thesis will show how added emphasis on continuous improvement between new product introductions can help the company achieve its cost reduction goals.

**Figure 1. Continuous vs. Breakthrough Improvement**



### 1.2.3 Modularity – Definition and Examples

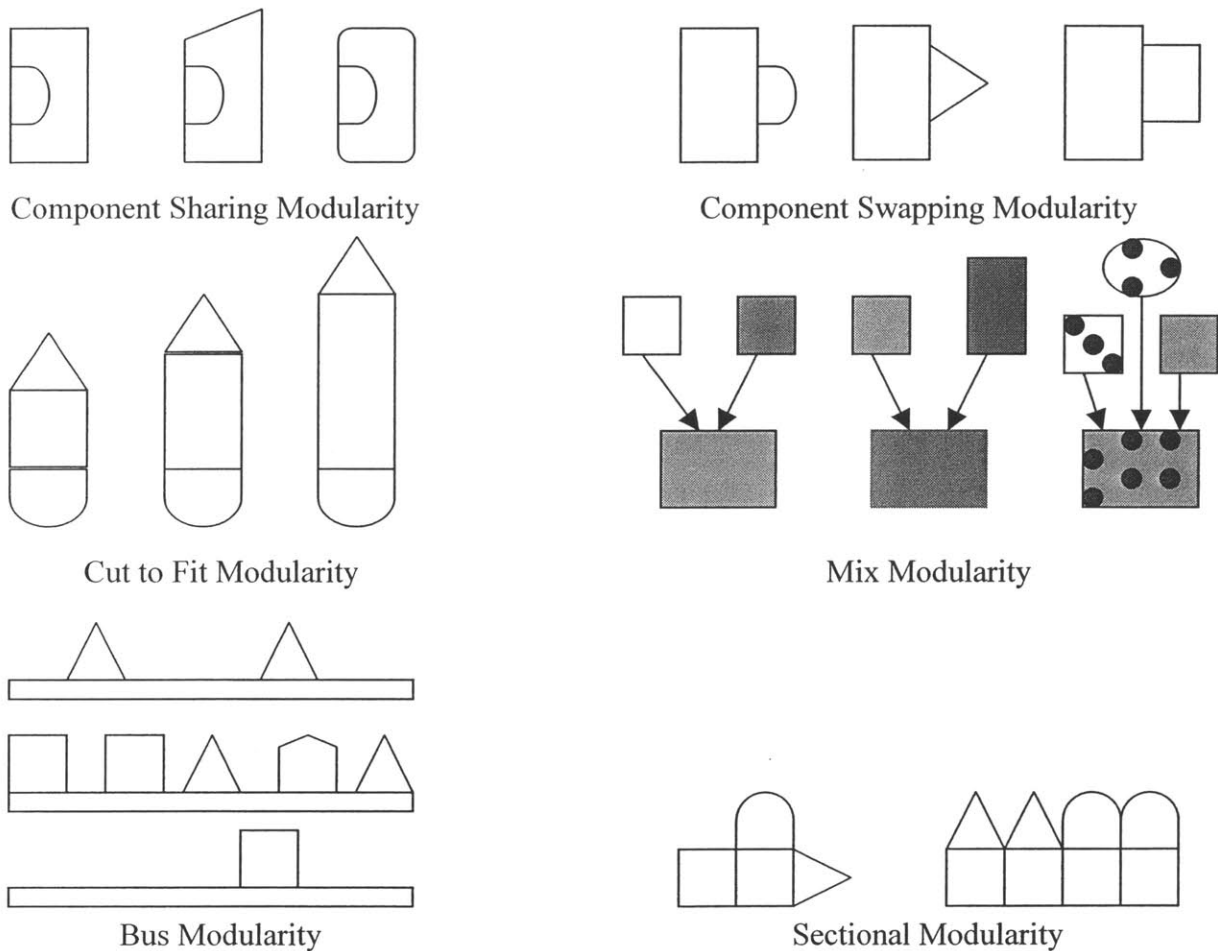
In *Mass Customization: The New Frontier in Business Competition*, B. Joseph Pine II identifies modularity as “the best method for achieving mass customization<sup>10</sup>”. He cites several examples of companies who have minimized costs while maximizing individual customization by creating (modular) components that can be configured into a wide variety of products.

Lutron Electronics Company in Coopersburg, Pennsylvania, produces over 11,000 different lighting control systems on a single assembly line from modularized, standard components. Lutron engineers work with individual customers to discover their needs and develop customized products for them. When Lutron has 100 or so models designed, engineering and production get together and “rationalize” the product line down to fifteen or twenty standardized, modular components that can be configured into the same 100 models that customers can purchase<sup>11</sup>.

Black & Decker put a number of competitors out of business in the 1970's by creating a new line of products out of standardized, modular components. As a result of simplifying, modularizing, and standardizing, they were able to produce 122 basic tools such as handsaws, drills, and sanders, out of a relatively small set of standardized components. Their costs plummeted while their variety increased<sup>12</sup>.

There are six different kinds of modularity<sup>13</sup>. Figure 2 shows simplified illustrations of each.

**Figure 2. Six Types of Modularity for Mass Customization<sup>14</sup>**



In component sharing modularity, the same component is used in multiple products. There are numerous examples of this type of modularity, such as common parts (tires, batteries, oil filters, steering wheels) in several models of automobile. Component swapping modularity involves pairing different components with the same basic product. Swatch

watches and personalized T-shirts are good examples. Levi's offers cut to fit modularity in its "Levi's Original Spin" custom-made jeans. Paint, fertilizer, and Mexican food are good examples of mix modularity. Bus modularity uses a standard structure that can attach a number of different components. Laptop computers with multi-use ports that can be used to plug in extra batteries, a floppy drive, or a compact disc drive are good examples. The final type of modularity, sectional modularity, provides the greatest amount of flexibility and customization. Standard interfaces are the key to achieving sectional modularity. Legos are the ultimate example. Standard interfaces, sometimes referred to as open architecture, are also the centerpiece of any platform strategy for customization and are part of the reason for the incredible pace of innovation in the computer industry.

### **1.3 Project Overview**

The project began as an attempt to understand the sources of complexity, rework, and flow disruptions in the design teams of the Wire Responsibility Center (WIRC). Production ramp-ups and new customer introductions are known to be the sources of increased complexity and rework in this area. New customer introductions and production increases require additional capacity from design teams and manufacturing groups. There is simply more opportunity for error and miscommunication between design and manufacturing teams during these events. The increased pace of operations during these events exacerbates the rework problem caused by errors and prevents effective continuous improvement. This project studies an initiative launched by the engineering leadership of the WIRC for the purpose of improving the process capabilities between engineering and manufacturing groups in the WIRC.

This initiative, called the Change, Error, and Rework (CER) initiative, is basically a vehicle for imbedding continuous improvement methods in the design teams and processes of the WIRC. It is currently viewed as a tool for reducing rework in the design teams by identifying the causes of errors and providing feedback to the design team responsible for them. The thesis contends that this reduction in rework is an opportunity to liberate needed resources for the pursuit of new designs that will enable cost-effective mass customization.



#### **1.4 Related Research**

Formalized, cross-functional continuous improvement efforts such as the one described in Chapter 4 can also be thought of as enablers to “concurrent engineering”. Fine and Cohen (1998)<sup>15</sup> discuss the attributes and benefits of “three dimensional concurrent engineering” from a product architecture perspective. The role of modular architecture in product variety deployment is shown by Fujita et al. (1999)<sup>16</sup>. Meyer and Lehnerd (1997)<sup>17</sup> have demonstrated the power of modular product platforms for enabling product variety and cost savings. Henderson and Clark (1990)<sup>18</sup> and Sanderson and Uzumeri (1995)<sup>19</sup> have also shown how the use of modular product platforms has given companies an edge on the number of products they can offer and on their profitability over competitors.

#### **1.5 Thesis Outline**

Chapter 2 provides background information for the company and describes the setting in which the project was initiated. Chapter 3 gives a detailed description of the complex processes and organizational structure of the Wire Responsibility Center. The CER initiative is described in Chapter 4, from its inception through the second iteration. Lessons learned from the events covered in Chapter 4 are then used to develop recommendations, which are presented in Chapter 5. Chapter 6 concludes the thesis by discussing the potential impact of successful implementation of cross-functional continuous improvement methods in other areas of the company.

## **2 Production Side of Integration to Support Mass Customization**

### **2.1 Company Background, Position, and Outlook**

The Boeing Company dominated the commercial aircraft industry for three decades. Its superior technology, world class customer support, and ability to provide customized products propelled the company to a market share of 60% throughout the 80's and into the 90's. Stiff competition from Airbus, however, is threatening Boeing's dominant position in the commercial airplane industry.

Several factors have contributed to this dramatic turnaround. Deregulation of the airline industry created a highly competitive environment for Boeing's biggest customers. Cost is now the main focus of the airlines. With cost of airplane ownership reaching 54% of the total direct costs of operating an airline<sup>20</sup>, cost reduction has become the predominant concern for commercial aircraft manufacturers as well.

Stiff price competition from a highly capable international competitor has added significantly to Boeing's need to reduce costs. In 1998, Boeing delivered a record number of airplanes, but made only .5% returns on \$58 billion in revenues<sup>21</sup>. Sales were not the problem – production costs were.

To succeed in this new competitive environment, Boeing must reduce the cost of ownership of new commercial aircraft. This will require major reductions in the cost of designing and manufacturing airplanes. To achieve these significant cost reductions, Boeing must fundamentally re-think the way it configures and produces commercial aircraft. In other words, it must fully embrace and achieve the goal of cost-effective mass customization.

#### **2.1.1 Mass Customization – Progress to Date**

BCAG has made significant progress in some areas toward the goal of cost-effective mass customization, especially on the production side of the business. In an effort to “provide quick response throughout the value chain” (#4 from Table 1), a company-wide Lean Production Initiative has been launched with the full support of a Lean Central Office and

significant organizational infrastructure and visibility. “Make-it-flow” initiatives on the 777 line have led to a 50% reduction in the number of days required to perform final assembly on a 777. Dozens of Kaizen teams are working on projects to reduce part counts and improve the efficiency of production processes. Boeing has retained the services of the Shingi Jutsu Co., a manufacturing consulting firm, to direct and monitor the efforts of employees on various lean production teams.

Continuous improvement is a vital component of any lean strategy. It is also a centerpiece for achieving cost-effective mass customization. Boeing has made significant progress in training its manufacturing workforce on continuous improvement methods and on implementing continuous improvement plans in production. On the engineering side of the house, however, the company has mostly relied on expensive “breakthrough innovations” and new product introductions. Prior to the earnings surprise of 1998, there was insufficient attention paid to design and engineering costs. Continuous improvement is a very powerful tool for cost reduction and is just now beginning to find its way over to the engineering side of BCAG.

The company has also formed cross-functional teams in order to create plans for achieving modularity of components (#5 from Table 1) and creating customizable products (#2). These teams represent a bold new attempt at integrating production and design, which will undoubtedly pay off handsomely in the end, but they haven’t had time to implement any of their ideas so far.

The bottom line is that the vast majority of the company’s continuous improvement efforts to date have centered on the production side of the business. While this is an important first step, no amount of improvement in manufacturing alone will be enough to achieve the necessary cost reductions. Cost-effective mass customization will only be accomplished with a coordinated effort between manufacturing and engineering.

## **2.2 The Wire Responsibility Center (WIRC)**

The WIRC designs, routes, and installs every wire and wire bundle on every model of airplane Boeing produces. It also fabricates about 70% of the wire bundles that are

installed on Boeing planes. There are hundreds of bundles on every model and up to 100 miles of wire on a 777.

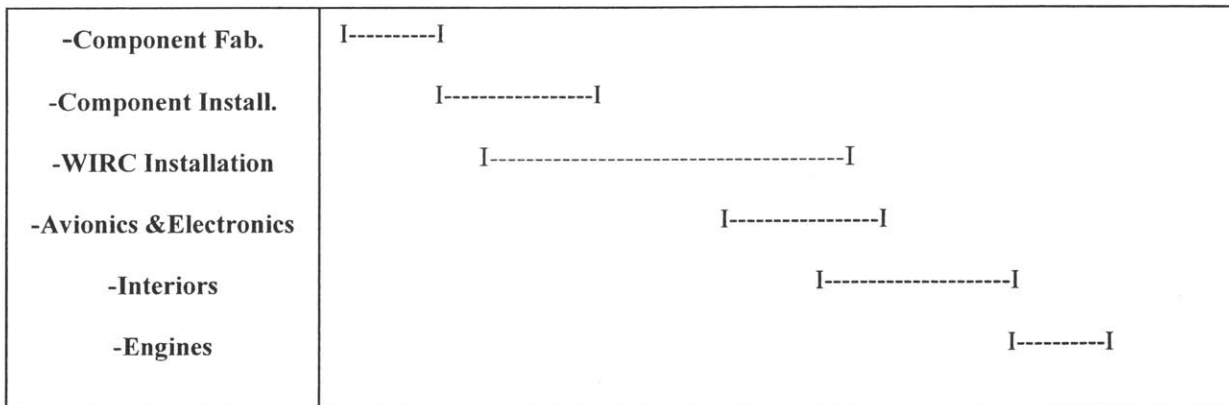
There are hundreds of wire types that carry everything from small signal currents to large power currents for running motors. Some bundles run the entire length of the airplane and have very few connections while others cover short distances and end with dozens of connectors that plug into electrical and avionics equipment.

The WIRC is one of many “responsibility centers” that provide components to Boeing’s final assembly plants. Its organization and information flows, which will be covered thoroughly in Chapter 3, are very similar to the structure of other responsibility centers, such as the Wing Responsibility Center (WRC). In this respect, the WIRC is a good representative sample of a typical Boeing design and production organization. It is also a very appropriate place to study the implementation of continuous improvement initiatives in an engineering environment at Boeing.

### 2.2.1 The WIRC’s Position in the Airplane Production Process

Figure 3 shows how the WIRC fits into the airplane production process.

**Figure 3. Overview of Airplane Production Process**



This very general representation shows how WIRC installations are performed throughout most of the airplane production process. More detailed diagrams of the WIRC’s design team structure and shop floor layout are presented in Chapter 3.

### **2.3 Unique Aspects of the Wire Responsibility Center**

Boeing's strategy of providing customized products results in an enormous amount of customized design work and engineering in all the responsibility centers. The WIRC is uniquely positioned at the end of the whip for most of these changes. This positioning gives the WIRC the distinct honor of being the best place within BCAG to study mass customization.

Nearly every custom design and mid-production design change that BCAG encounters affects the WIRC in some way. For example, upgrades in avionics packages or technology require new combinations and designs of the supporting wiring. Similarly, changes in in-flight entertainment (IFE) options are frequent and also require corresponding design changes in the WIRC.

Even changes that do not involve electronics require design changes in wire bundles. Under Boeing's current system, new bundle drawings and designation numbers are required whenever the length of a wire bundle is changed. If a customer chooses to move a "monument" (a galley or a lavatory, for example), any wiring that was routed to go around the monument must be re-routed. This re-routing affects the length of the wires in these bundles, which requires a new bundle design from the WIRC.

The average wire bundle undergoes 15 design changes prior to installation. The bundle that connects the cockpit to the rest of the airplane averages 80 design changes. These changes dramatically impede the flow of information and output of the design teams in the WIRC.

### **2.4 Project Focus - Advanced Design Change Notifications (ADCN's)**

The vast majority of these changes take place prior to any physical handling of wire and only impact the design teams. Changes that occur after wire is cut affect the product flow of the shop in addition to the flow of output from the design teams. For example, if a customer's needs change during production (their marketing data says to add more first-class seats), any bundles that require rerouting as a result of this change would need to be

redesigned. These changes require an Advanced Design Change Notification, known as an ADCN.

Advanced design changes can be generated for a variety of reasons, such as customer requests. There can be a year or more of lag time between order placement and the end of production of airplanes. New innovations in avionics and electronics occur during this lag time and must be incorporated into the production system. Customers also request new seating arrangements and layouts for galleys and lavatories (called “footprints”) in order to differentiate themselves from their competitors.

As will be shown in Chapter 4, a large number of ADCN’s are generated internally. As part of Boeing’s efforts toward lean production, the WIRC has a system for communicating feedback from the shop to the engineering/design teams in order to enhance DFMA, Design for Manufacturability and Assembly. These “squawks” can lead to the production of an ADCN. Squawks that identify out-of-date reference numbers on design drawings are one example. The focus of this project is ADCN’s that are generated in order to resolve errors made internally by the design teams.

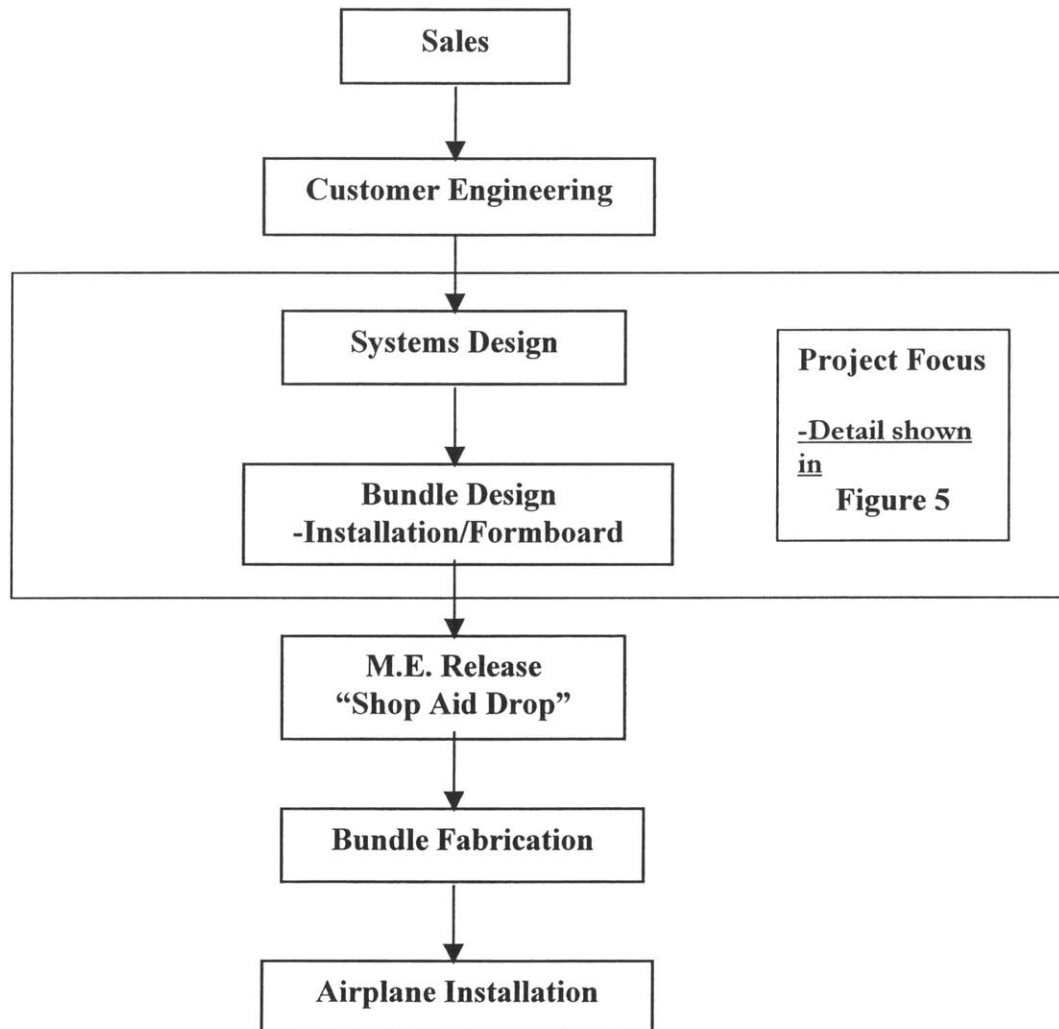
Chapter 3 will provide a description of the organizational structures and information flows of the design teams and of the shop floor. This background information will facilitate the discussion of the WIRC’s continuous improvement initiative in Chapters 4 -6.

### 3 Development Side of Integration to Support Mass Customization

#### 3.1 Overview of WIRC Development Processes

Figure 4 provides a very general overview of information and material flows in the design teams of the Wire Responsibility Center. The figure depicts an ideal scenario, in which design drawings flow smoothly from one area to the next. Figure 5 will show how this complex this straightforward-looking process really is and how changes and feedback from downstream customers can disrupt the process.

**Figure 4. Overview of WIRC Processes**



Sales and customer engineering work with customers to define the airplane orders and general systems to be designed and produced. This is the product definition stage where seating arrangements (number of first class seats vs. coach and business class) and “footprints”, which specify locations of galleys and lavatories, are specified.

Systems Design then takes this information and generates more specific drawings that provide a macro level guideline for integration of the systems ordered. These schematics define the routing and connection points for each bundle, for example.

Systems Design provides 3-D computer-generated designs to the Bundle Design groups. The groups in Bundle Design are responsible for several types of drawings that are used on the WIRC shop floor. These include formboard drawings, attach point drawings, and production illustration drawings.

Formboard drawings are used to specify wire type and length and provide a blueprint for fabrication of the wire bundles (wire bundles are built on large boards called formboards). Attach Point drawings specify how the bundles are to be supported by and attached to the airplane’s structural components. Production Illustration (PI) drawings include all the information factory workers need to install the wire bundles in a section of the airplane. Each of these steps is an opportunity for workflow to be interrupted by upstream errors. Systems Design and Bundle Design are the focal areas of the project and are presented in more detail in Figure 5.

Figure 5 illustrates the degree of complexity involved in designing electrical wiring systems for commercial aircraft<sup>22</sup>. The figure depicts only the processes from the Systems Design groups (from Figure 4) on the left to M.E. Release “Shop Aid Drop” on the right. This figure, like Figure 4, only shows the optimal situation.

Even in an ideal scenario, the interdependence of the various functional groups and the timing of drawing releases from upstream processes lead to a high degree of iteration within the WIRC design organization. For example, Customer-driven ADCN’s are generated in the Systems Design groups, shown as “diagram release – avionics”, for example, on the left side of the figure. It must then pass through 12 separate areas, from





Customer-driven changes are especially difficult to incorporate into a process with this degree of interdependence and complexity. Industry cyclicity is especially painful for the design teams in the WIRC due to the complexity of the process as well as the significant amount of training time that is necessary to become proficient within the system. Rework and errors add another layer of complexity and cause further disruptions and more iteration. Any reduction in rework and errors achieved by applying continuous improvement methods to the design organization in Figure 5 would allow the teams to focus on designing modularized components that are necessary for mass customization.

From Bundle Design, the drawings travel to ME (Manufacturing Engineering) Release where they are reviewed for release to the shop floor. This is also referred to as “Shop Aid Drop”. Bundle Fabrication follows the release of the drawings to the shop floor and Airplane Installation is the step where wire bundles are actually installed on the airframe.

### **3.2 Feedback Systems/Interfaces**

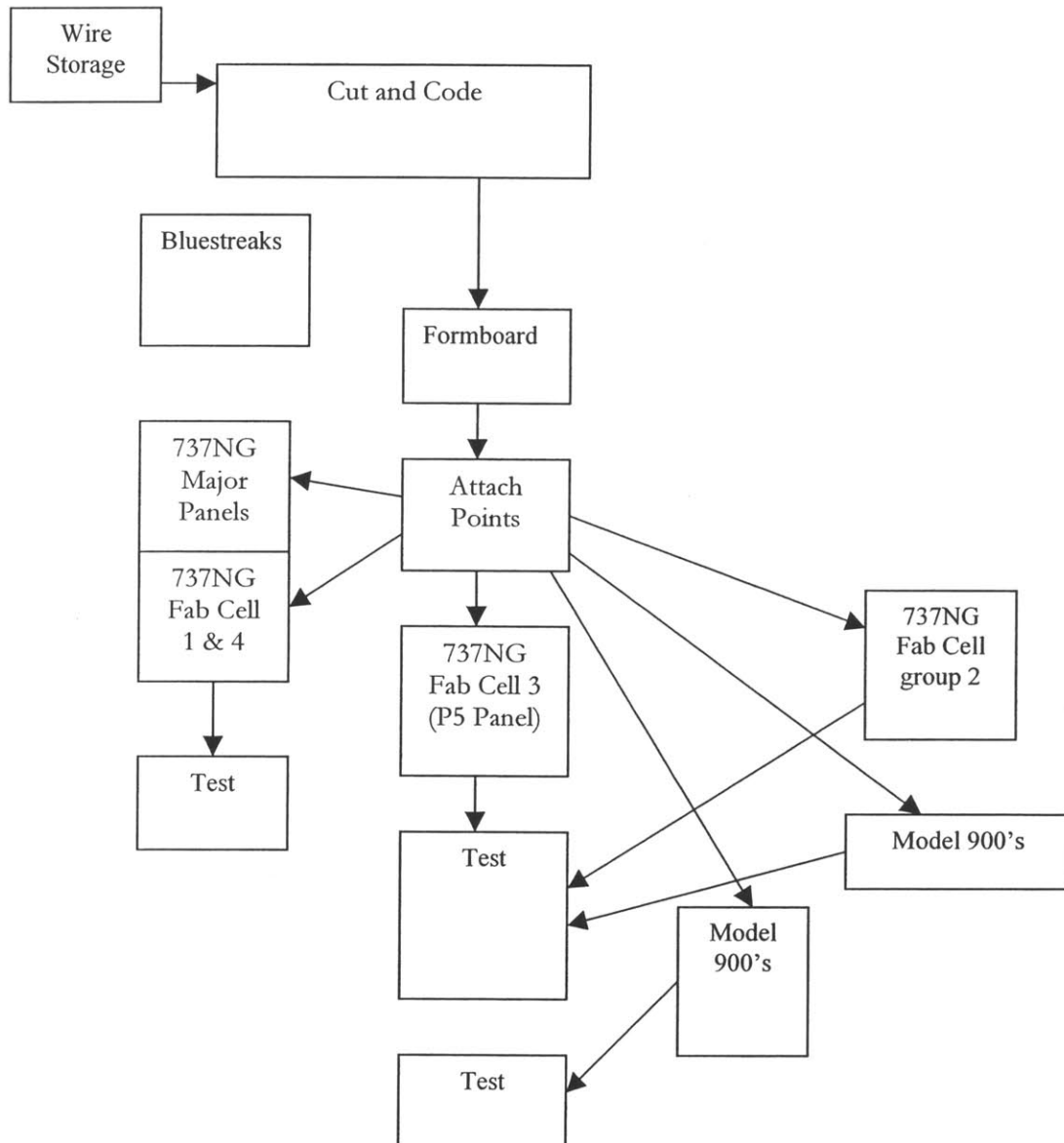
Providing timely and efficient feedback is also extremely difficult and time-consuming in this organization. The majority of the work is done in sequence with months between completion of tasks<sup>23</sup>. In addition, each step is difficult in and of itself, so very few people are able to provide feedback to members of teams other than their immediate suppliers<sup>24</sup>. The sheer volume of change that impacts the WIRC due to its unique position at the end of the whip for most design changes also exacerbates the problem. This is especially evident during production ramp-ups (as in 1998), which are difficult to prepare for and very unpredictable.

### **3.3 WIRC Shop Floor Layout**

Figure 6 shows a basic layout of the WIRC shop floor<sup>25</sup>. The common operations in WIRC production are: cut and code, formboard, and attach points. Final assembly and test are performed in separate work cells that are grouped by bundle type. The “model 900” designation, for example, is for complex bundles that connect electronics boxes and power panels to other electric components. The “bluestreak” area is reserved for bundles that require major late-stage design changes and/or extensive rework.

Fabrication begins with “cut and code” on the top of the figure. This is where the properly coded wire is identified, drawn from storage, and cut to length. The “formboard” area is where wire is routed around pegs placed in large boards and grouped into bundles. Attach point hardware (connectors, etc.) is affixed next. From here the bundles go to their family station (737NG group 1,2,3,4, 737NG major panels) for final assembly and testing.

**Figure 6. WIRC Fabrication Shop Floor Layout**



### **3.4 The Electrical Corrective Action Team (ECAT)**

In response to the drawing interpretation difficulties that were being experienced in the factory, the Electrical Corrective Action Team (ECAT) was set up to provide real-time “ship-side support” to manufacturing teams on the shop floor. The team is comprised of engineers from the design teams. They are on-site in the factory to resolve technical questions, clarify drawings, and answer questions. They also coordinate and direct feedback from the shop to the appropriate design teams.

Currently, documented feedback comes in the form of “shop squawks”, as mentioned earlier. Squawks are categorized by defect type and tallied by ECAT in order to identify defect patterns and increase the quality of the drawings released from shop-aid drop. There are four categories of squawks. “F-type” squawks are called “producability squawks” and are provided to help the design team’s DFM efforts. The other three types of squawks document drawing errors such as incorrect reference numbers, missing lines or specifications, and missing or mislabeled components (such as connectors).

Squawks that can only be resolved with major re-design work can generate ADCN’s. For example, if a wire type or gage was specified incorrectly and improperly incorporated into a bundle, the entire bundle would have to be reprocessed under an ADCN. If there were sufficient time to reproduce the bundle using “normal” processes, the work package would be queued at the beginning of the line at “cut and code”. If the job is more urgent, it will be handled as a “bluestreak”.

These squawks are the first attempt at formalizing cross-functional continuous improvements between the engineering and manufacturing teams in the WIRC. They provide documented feedback from the production floor to the design teams in order to improve the quality of the output from the design teams and reduce rework, costs, and lead times. Their effectiveness is limited, however, since errors that reach the production floor have already made it through the entire process and possibly caused secondary errors. A formalized system for catching errors as soon as possible would be much more effective. The additional resources that would be liberated by such a system could be used to pursue improved designs that would enable cost-effective mass customization.

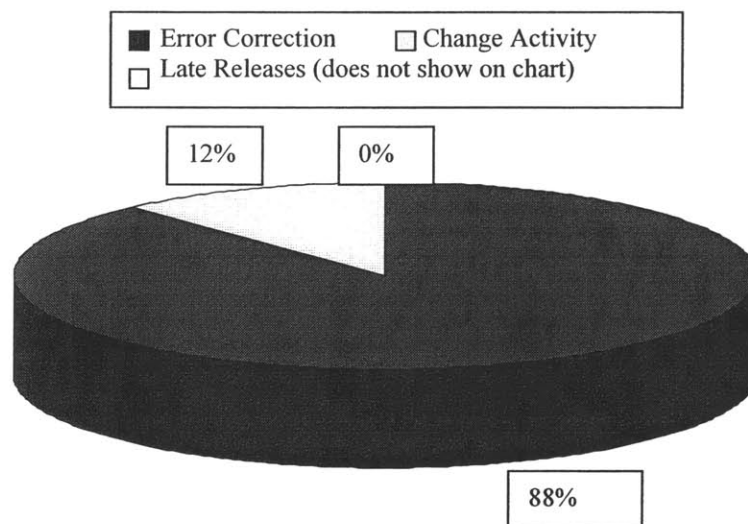
## 4 Analysis of Difficulties in Integration to Support Mass Customization

### 4.1 Problem Discovery

BCAG experienced an unprecedented ramp-up in airplane production in 1998 and 1999, shipping a record of 569 commercial airplanes in 1998 and another record 620 planes in 1999. The WIRC, with its complex, iterative processes and unique position at the end of the change whip, became one of the bottleneck processes in commercial airplane production, with lead times between six months and a year<sup>26</sup>. The organization was able to settle in to the increased pace by Q2 of 1999, and its leadership was able to begin searching for opportunities to cut costs and improve performance.

Figure 7 shows the results of an inquiry by the WIRC leadership team into the causes of ADCN's for the 737NG-model airplane. It shows that 88% of the ADCN's for a given airplane were, on average, caused by errors in the documents delivered to production. Only 12% were due to customer changes. Late releases were insignificant.

**Figure 7. Sources of ADCN's for the 737NG\***



\* Data extracted from internal Boeing database. See Appendix 1 for data collection methods.

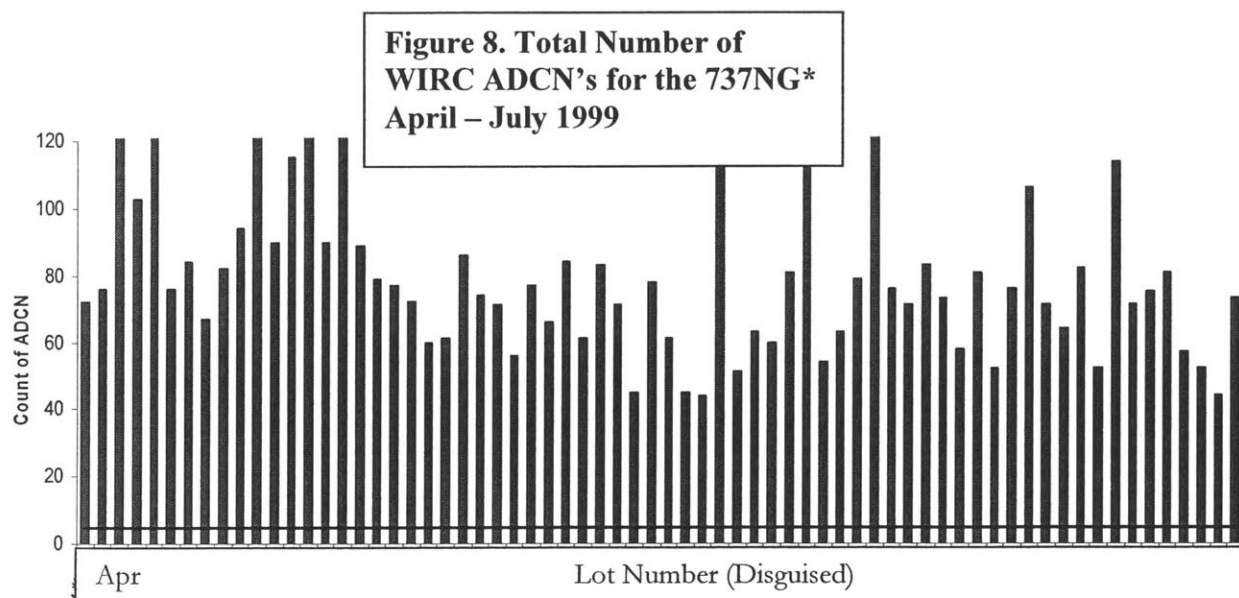
The results shown in Figure 7 were a surprise for the leadership of the WIRC design teams. The entire organization expected these results to show customer-driven change activity as the clearly dominant cause of ADCN's.

The data shown in Figure 7 was extracted from a database used to track ADCN's. As is explained in Appendix 1, ADCN's that affect multiple bundles are recorded in multiple places and were counted multiple times. The number of ADCN's resulting from errors is slightly exaggerated as a result of the data extraction method used, but the discovery of errors being a greater cause of ADCN's than change activity is still valid.

#### 4.2 The Change, Error, and Rework (CER) Initiative

As a result of this discovery, the Change, Error, and Rework (CER) Initiative was launched in June of 1999 for the purpose of reducing the number of errors being generated in the Production Illustration (PI) design groups of the WIRC. Recall from Figure 5 that Production Illustration (PI) drawings include all the information factory workers need to install the wire bundles in a section of the airplane.

Figure 8 shows the *total* number of WIRC ADCN's after shop-aid drop for the 737NG model from April through June 1999. As the figure shows, the average number of ADCN's per airframe is roughly 70.



\* Data extracted from internal Boeing database

The purpose of this chart is to show the average number of ADCN's that were being generated by the WIRC on the 737NG model airplane prior to the implementation of the CER Initiative. As will be shown in Figure 11, significant improvements in the number of ADCN's being generated by the WIRC were achieved simply by monitoring the output of the design teams in Production Illustration and providing feedback to their upstream suppliers in order to improve the output of the entire design team of the WIRC.

The data shown in Figure 8 is a simple tally of WIRC-generated ADCN's per airplane. All changes in design and production procedures of airplanes must be documented and sent to the customer upon delivery. These changes are stored in a database that represents the work package for the airplane affected. Each work center in Boeing has its own reference number which it uses to record each ADCN it generates.

The variability shown in Figure 8 is known to have several causes such as increased production rates and new customer introductions. There is simply more opportunity for error when designing new products and producing more products. Even during level production on well-known products, however, there are still 40-50 ADCN's being generated by the WIRC per airplane. Since roughly 88% of those are caused by errors as shown in Figure 7, an effective program for eliminating errors could have a significant impact on the design and production costs of the WIRC.

#### 4.2.1 Cost Impact of Errors

The cost implications of these errors are enormous and are shown in Table 2<sup>27</sup>. These figures were obtained by estimating the impact of reworking a drawing at 1.5 hours per reworked drawing and then multiplying that number by the design groups' run rate (costs of operation).

These cost estimates, while significant, do not include the lost opportunity costs caused by these errors. The flow disruption of these errors alone increases the lead times for getting products to the customer. Rework also causes confusion in estimating component costs and production costs for individual airplanes accurately, which has also been a huge

problem for Boeing in recent years. Feedback and continuous improvement are hindered when ECAT members are constantly fixing and documenting errors.

**Table 2. Estimated Cost Savings From Reduction in WIRC ADCN's 737NG Program**

	40-70% reduction*	90% reduction	90% reduction	90% reduction
	Jul-Dec 1999	2000	2001	2002
EE	\$10,388	\$208,915	\$269,770	\$279,583
ME	\$19,766	\$766,912	\$826,522	\$784,566
ECAT	\$12,885	\$361,665	\$284,595	\$207,590
Total WIRC	\$43,039	\$1,337,493**	\$1,380,887**	\$1,271,739**

\* First year of inception. Numbers shown in this column are actuals through October 1999.

\*\* Figures in these columns increase or decrease due to projected sales and sales mix.

Eliminating these errors by formalizing a method for cross-functional continuous improvement between engineering and production would also allow the WIRC to pursue the ideal goal of mass customization.

### **4.3 The First Iteration**

The CER team's first step in their effort to reduce the number of ADCN's caused by design errors was to categorize the errors. When an error is found on the shop floor or in an upstream process, a member of the CER initiative records the cause of the error. This data is then used to generate feedback to the designers. Figure 9 is an example of a CER initiative feedback form<sup>28</sup>. It shows the errors generated by one illustrator over a period of one month.

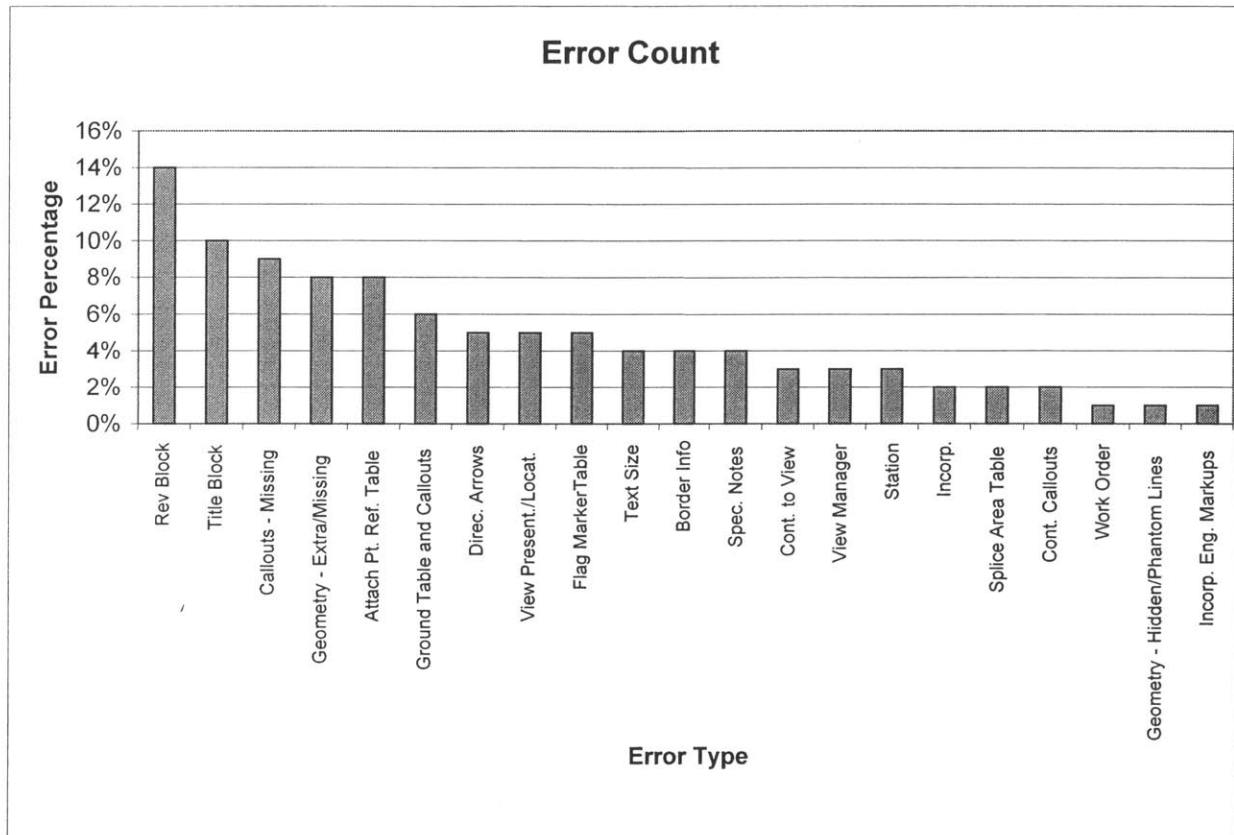
The graph also serves as a pareto diagram and highlights the most recurrent errors. The WIRC used this data to identify problem areas within the design teams in an attempt to increase the number of error free drawings being released to the shop floor.

This first attempt simply identified all errors in order to get a handle on the types of errors that were occurring. Some of the errors, such as Rev. Block, Title Block, and Text Size are more administrative in nature and have more impact on the design side of the WIRC than on the manufacturing side. These errors create problems in matching design drawings to the proper bundle and lot number on the shop floor but are generally easier to eliminate



than errors involving actual design flaws. The Rev and Title Block errors, for example, are new and are part of an effort to reuse design drawings. The classification system employed by this drawing reuse effort is extremely complex, but there is enormous cost saving potential in being able to reuse design drawings. These errors are expected to decline as the designers gain more experience with the classification system.

**Figure 9. Sample CER Initiative Error Type Feedback Form**



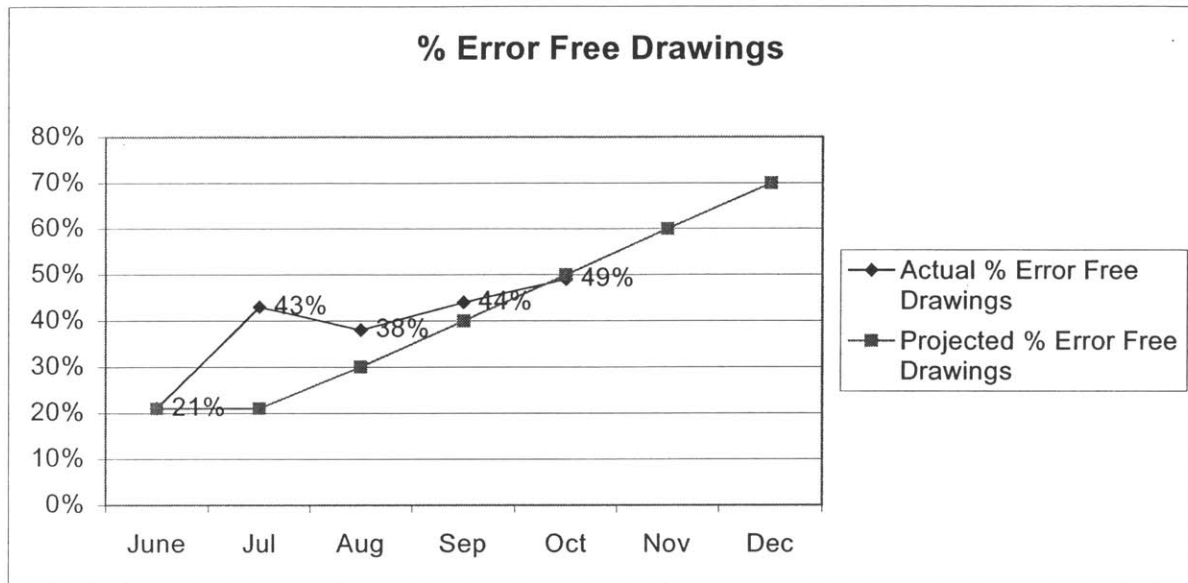
Other errors, such as Callouts, Geometry, and View, involve actual design flaws such as missing parts or missing or incorrect geometric specifications. These errors are more complex and require more experience, training, and skill to eliminate than other more administrative errors. These issues will be discussed further in Chapter 5.

#### 4.3.1 Initial Results

The discovery of design errors as the leading cause of self-induced rework and subsequent focus on error feedback by the CER team had an immediate and dramatic impact on the quality of the WIRC's drawings. Figure 10<sup>17</sup> shows the step increase in the percentage of

error free drawings in the month of July, 1999, which was the first month after the WIRC design teams received their packaged feedback from the CER team.

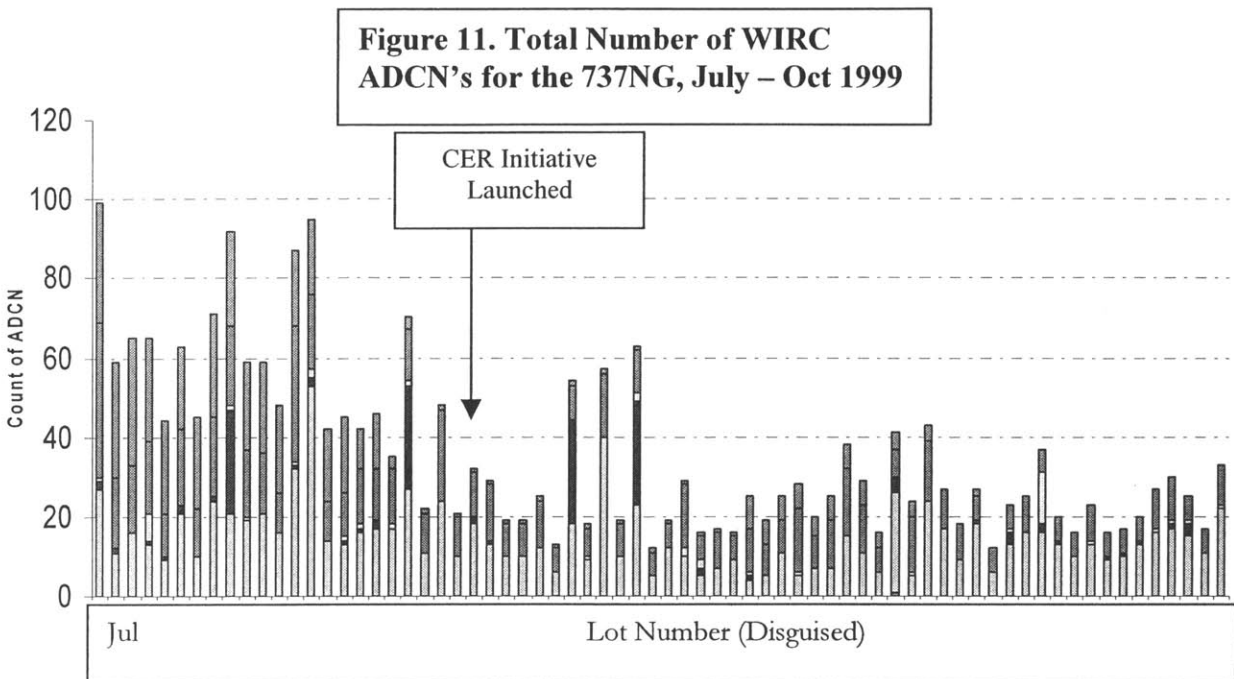
**Figure 10. Percent of Error Free Drawings**



The projected line is the target set by the leadership of the WIRC design teams. The data was calculated by members of the CER team. The percentage of error free drawings was determined by designating each drawing with no errors as error free, and dividing that number by the total number of drawings produced that month.

As the graph shows, the WIRC's percentage of error free drawings more than doubled in July. Since the initial focus of the CER initiative was to reduce the number of ADCN's caused by drawing errors, it was then necessary to determine whether the increase in error free drawings actually translated into a reduction of ADCN's. Figure 11 was generated using the same methods that were used to generate Figure 8.

Figure 11 is a continuation of Figure 8 and shows the total number of ADCN's per airframe from the beginning of the CER initiative in July through Dec. 1999.



As the graph shows, the number of ADCN's per airplane was reduced from an average of 70 to an average of approximately 20 immediately following the first iteration of the CER initiative. This 70% reduction in ADCN's was achieved by formalizing a continuous improvement methodology between the manufacturing and design teams of the WIRC.

#### 4.3.2 The Rest of the Story

A surprising discovery was made upon investigating the impact of the CER initiative on the shop floor. Minimal impact was expected initially since the first step of the process was to clear up the clutter of rework on the design side of the equation in order to get a clearer picture of the root causes of errors and design rework. Negative impact on the shop floor was not expected, however. In its zeal to reduce the total number of ADCN's on the 737, the CER team also eliminated the F-type squawks and ADCN's that provide DFM feedback from the shop to the design teams. This caused some concern and negatively affected the CER initiative's image in the eyes of employees on the manufacturing side of the WIRC.

Eliminating the overall clutter caused by all types of ADCN's was a sound strategy, but the strategy was not communicated properly to ECAT or to the shop floor. If the elimination

of producability ADCN's had been communicated as a temporary event with the long term goal of improving the percentage of error free drawings sent from the design teams to manufacturing, the transition would have been better received and supported in the shop.

#### 4.3.3 Lessons Learned

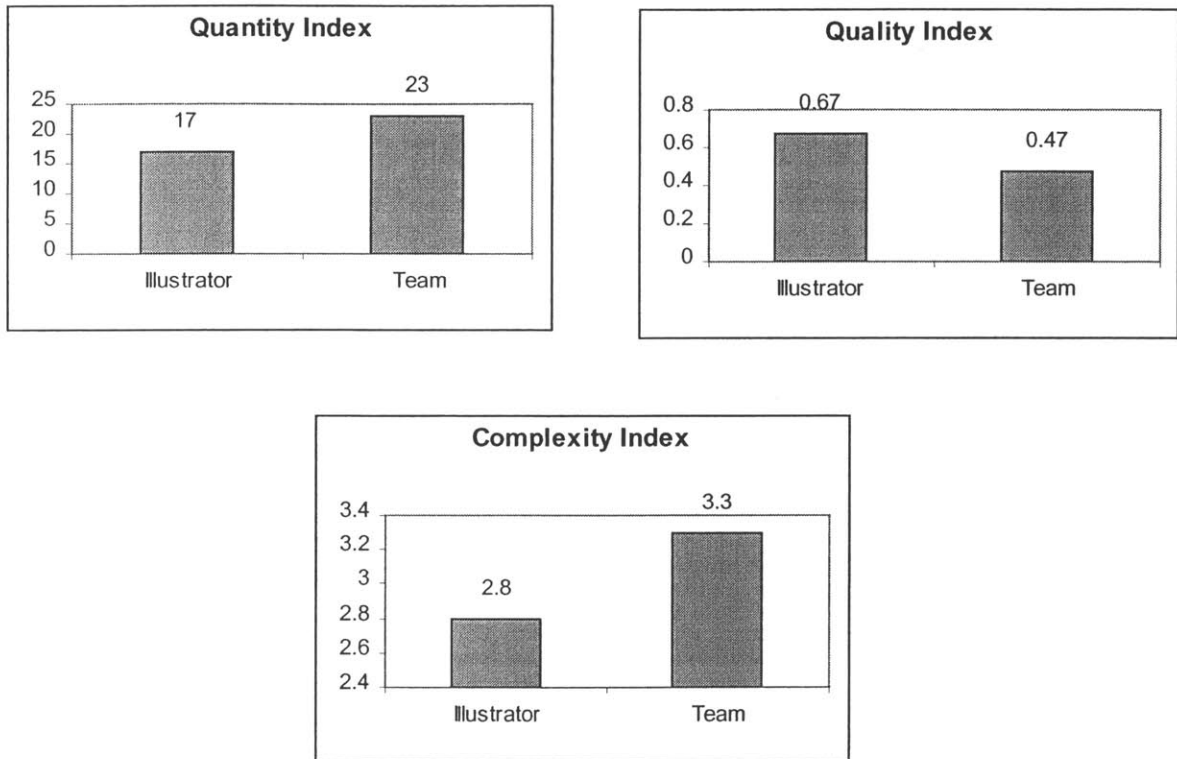
There were also some concerns in the design teams around the analysis of data on the sources of errors. Designers were concerned that their career evaluations would be unfairly affected by the new error performance measurements. One concern revolved around differences in complexity between the designs of some wire bundles versus others. Another similar concern centered on complexity differences between these design changes.

These concerns were addressed by the addition of simple quality, quantity, and complexity indices to the CER feedback forms. The indices compare each individual illustrator's performance to the overall performance of the team. Members of the CER team assign complexity values to each drawing based on the size and scope of the design job. These complexity scores range from 1-5. The complexity index comparison values are simply the result of adding up each complexity score and dividing by the total number of drawings scored. The quantity index is a comparison of each illustrator's output to the average output of the team members, by sheer number of drawings produced. The quality index is the number of errors per drawing produced.

Figure 12 shows an example of the complexity index and individual to team comparisons on a new and improved CER feedback form.

The addition of these comparison indices, along with assurances from management that the data collected from CER would primarily be used for team-based continuous improvement efforts and not for individual performance evaluations, alleviated the tension that can be associated with receiving individual performance feedback.

**Figure 12. Sample of Improved CER Feedback Form**



#### 4.3.4 Next Steps

The CER team must continue to pursue the continuous improvement process it has begun under the CER initiative. It has achieved a doubling in the percentage of error free drawings simply by monitoring errors and providing feedback to the design teams. Looking back at Figure 10, however, will show that there is still room for improvement.

As the figure shows, the WIRC error free drawing percentage has stabilized in the 40-50% range since the initial step improvement seen in July. Achieving the stated short-term goal of 70% and the long-term goal of 100% will require further improvements in the CER process. Reintroducing the producibility ADCN's that were put on hold will aid the WIRC's efforts to reduce errors by reopening the lines of communication between the design teams and the shop floor.

The additional design team capacity that has been realized by reducing the clutter and rework caused by errors and miscommunication can now be put to work improving the CER process. The complexity indices are an example of an improvement to the process

that requires additional time but can now be accomplished since the extra time has been made available by reducing rework caused by errors. The more experienced designers can devote more of their time to training and developing new ways to eliminate or detect errors at their source. Designers can spend more time understanding their customers' needs and processes in order to find new ways to eliminate errors caused by miscommunication or misunderstanding.

The continuous improvement cycle that was launched by the CER initiative has enormous potential for cost savings in the WIRC, as shown in Table 2. The CER initiative is also a great opportunity to formalize tighter working relationships between the design teams and manufacturing teams of the WIRC. If used for the purpose of realizing efficiency gains in the relationship between design and manufacturing, it also has tremendous potential for enabling the WIRC to achieve the ultimate goal of cost effective mass customization.

## **5 Solution to the Difficulties of Integration to Support Mass Customization**

### **5.1 Short Term Opportunities**

The additional design team capacity realized through the continuous improvement process of the CER initiative can be used to accomplish significant improvements in the efficiency, productivity, cost performance, flexibility, and quality of the entire WIRC.

#### **5.1.1 Integration of Thinking and Doing**

As the WIRC design teams become more comfortable with receiving and incorporating feedback, the CER team can focus its efforts on eliminating the problems that have the greatest impact on the shop floor. As mentioned in section 4.3.2, the negative impact of temporarily eliminating producibility ADCN's created some concern among ECAT members on the shop floor. Once the shop experiences a reduction in drawing errors and ADCN's, the WIRC will have the opportunity to better integrate the efforts of its design teams with its manufacturing teams.

Once the WIRC gets a handle on the situation by eliminating the errors that are easily fixed, it could begin to regroup errors according to impact/cost. The CER team could categorize errors by the amount of disruption they cause to each functional group in the WIRC. Errors could first be categorized as Administrative or Technical. This could help identify the source of new errors more quickly. For example, if a new classification system for reusing drawings is initiated and the number of administrative errors spikes, the CER team could immediately identify the new classification system as the source.

Since total WIRC engineering costs are 150% of WIRC shop floor costs<sup>30</sup>, errors that affect the design teams will generally have greater cost impact than errors that affect the floor. Communicating this fact and the overall goal of the CER process to the shop would allow the members of manufacturing teams to understand why the CER initiative must concentrate on errors that affect the design side first. The shop will also be better able to communicate which errors impact it the most. Errors that cause major disruptions in the

shop (called “Bluestreaks”) would be targeted for elimination before errors that have limited effect. For example, more emphasis should be placed on errors that result in cutting the wrong type of wire or cutting the wrong length of wire, such as missing geometry or bad reference numbers, than on errors such as text size which have little or no effect on the costs of the WIRC.

## **5.2 Long Term Possibilities**

The clarity of a stable process provided by the CER initiative has enormous potential to improve the way work is accomplished in the WIRC. One intriguing possibility is the attachment of financial incentives to future improvements in cost reduction or productivity achieved by the functional teams of the WIRC, the WIRC as a whole, or a combination of both.

The complexity index could be modified and used as a classification system to classify wire bundles according to complexity. This would allow the members of the WIRC design teams the opportunity to pinpoint troublesome bundles. The design teams would then be able to anticipate flow problems caused by bottleneck bundles and make arrangements to handle them separately. One possibility would be to reorganize the teams around the complexity classification system. Designers with more experience, expertise, or a stronger desire to challenge themselves by solving complex problems could be assigned to the teams that handle these problem bundles. Designers with less experience, less training, or a strong affinity for volume production would be assigned to teams that crank out more routine product.

Another possibility for realigning the workforce would be to classify bundles according to their change history. Bundles that have a track record for late-stage changes could be identified and handled by team members who enjoy the challenge of fast-paced change and are better able to deliver in that environment. This knowledge on bundle change history could also be used to identify which bundles are the most important to customers. A special process or team could handle bundles that serve important features that tend to change in late stages of the production process. These bundles could be targeted as



candidates for design changes that make them more robust and able to handle late-stage changes and feature additions.

Taxonomy of bundles by complexity and/or change history would also allow the planning organization to load work into the system more advantageously. For example, holding the bundles that tend to change until the end of the load would prevent the WIRC design teams from working on designs that are likely to change on them after the design work is completed.

### **5.3 *Enabling Mass Customization***

The WIRC design organization will also be able to use its newfound resources and capacity to achieve its ultimate goal of cost-effective mass customization. “Quick response throughout the value chain”, from Table 1, will be enhanced through increased feedback, communication, and cooperation between manufacturing and design team members. This relationship has the potential to evolve into a virtuous cycle of continuous improvement and lean operations in design and manufacturing. Increased efficiencies in design and manufacturing can result in quicker feedback and a value chain that is more responsive to the customer. The design teams can use the capacity that was formerly devoted to rework on enhancing their DFM efforts, which will result in even more efficiency improvement and quicker response throughout the value chain.

Another general method for achieving mass customization is to “modularize components to customize end products and services”, which is #5 from Table 1. Newly realized capacity in the design teams of the WIRC could be used to develop a platform strategy for major electrical components, such as cockpits and “EE Bays”. This strategy could include open architecture “plug-and-play” concepts like those that are prevalent in the computer industry. A defined interface strategy could also be employed in order to reduce some of the variation that occurs when new avionics or electronics are introduced.

Creating customizable products is another general method for achieving mass customization. Efficiency gains in the WIRC design teams would allow team members to pursue ideas such as using low-frequency radio waves instead of wires for signal

transmission to electronic components. The device used to send the signals could be standardized, with inexpensive and easy-to-produce upgrades to software packages providing the customization instead of expensive hardware that is slow to market. Embedding programmable computer chips and/or CPU's into major electrical components could provide additional flexibility and opportunity to exploit the cost-effective mass customization that is provided by software.

The CER initiative has tremendous potential for formalizing a cross-functional continuous improvement program that improves the relationship and communication between design and manufacturing teams. This is arguably the most beneficial aspect of the CER initiative. Mass customization can only be achieved through close relationships between functional groups in an organization. Formalizing this relationship through efforts similar to the CER initiative can also be adopted by the rest of Boeing's Commercial Airplane Group.

## 6 Conclusions

### 6.1 *Continuous Improvement in Engineering*

The continuous improvement efforts described in this thesis are unique in some ways, and not in others. They are certainly not the first or only such efforts that have occurred within the Boeing Commercial Airplane Group. They do represent, however, an excellent baseline study for evaluating other similar projects or identifying continuous improvement opportunities in other areas. Mass customization can be achieved throughout BCAG by using initiatives like CER to formalize cross-functional continuous improvement relationships between engineering and manufacturing teams.

Many companies, including Boeing, are structured in such a way that functional groups are more isolated from one another than an ideal situation would warrant. Company size, degree of specialization required to carry out tasks, logistical concerns in terms of historical facility layout and industry evolution, and organizational rigidity are all causes of this phenomenon. Optimizing each of these functional groups will be enough in some industries and time periods. Eventually, however, some companies will reach the point where their best opportunities for improved performance lie in enhanced relationships between functional groups. Achieving mass customization is impossible without seamless, highly productive, “boundaryless<sup>31</sup>” working relationships between functional groups.

The question then becomes one of initiative. Should manufacturing, for example, dictate improvement opportunities to engineering or should engineering place the impetus for providing appropriate feedback on manufacturing? This may seem to be a rather trivial question, but its answer has profound effects on the subsequent design of a continuous improvement initiative. If not handled appropriately, the initiative itself may suffer irreparable damage right from the start.

The leadership of the WIRC engineering teams should be commended for their efforts in successfully implementing the CER initiative. By focusing the spotlight for improvement on themselves initially, they created an atmosphere of cooperation between the engineering and manufacturing teams within the WIRC. They could have easily pointed to the flaws in

the manufacturing processes of the shop as the cause of the WIRC's problems. Instead, they got the continuous improvement ball rolling by streamlining themselves first. The foundation for improved performance throughout the WIRC has been set. Mass customization will only be achieved through similar efforts throughout the company.

## **6.2 *Impact on BCAG's Profitability***

Regardless of which side of the organization takes the first step, initiatives like CER have tremendous potential for achieving mass customization. If the CER initiative is successful as a vehicle for formalizing a cross-functional continuous improvement program between the engineering and manufacturing teams of the WIRC, it could be communicated to and adopted by other groups within BCAG. Even if the ultimate goal of mass customization is not reached in its entirety, there is tremendous potential for improved cost performance by increasing the efficiency of the working relationships between the functional groups of BCAG.

## 7 Appendix

The data in Figure 7 was extracted from a database that tracks ADCN's in the WIRC. Each ADCN that affects a particular wire bundle is listed under the work package log number for that bundle. ADCN's that affect multiple bundles are listed multiple times. As a result, an ADCN that was generated as a result of an error could be counted multiple times while an ADCN that was generated by a change activity could be counted only once. This phenomena could potentially skew the results in this case to show a greater impact for ADCN's generated by errors than for ADCN's generated by change activity. The reverse is equally likely. I have assumed in my analysis that this effect is equally likely for both types of ADCN's and therefore does not impact the ratio of error-driven ADCN's to customer change-driven ADCN's.

Even though the data is entered by multiple operators, the procedure is straightforward and the likelihood of error is the same for all types of ADCN's, so I have assumed that the ratio of error-driven ADCN's to change activity-driven ADCN's is unaffected by variation in data entry.

The data extraction is reliable and verifiable as can be shown by repeating the procedure and obtaining the same results. The procedure for extracting the data involves proprietary information and cannot be disclosed publicly here. The programs used are proprietary to Boeing but are very similar to normal, everyday database products that can be obtained on the open market.

## 8 Endnotes

1. The term “mass customization” was coined by Stanley M. Davis in *Future Perfect* (Reading, Massachusetts, Addison-Wesley, 1987).
2. Stan Davis, Forward to *Mass Customization: The New Frontier in Business Competition* (Boston, Massachusetts, June 1992).
3. B. Joseph Pine II, *Mass Customization: The New Frontier in Business Competition* (Boston, Massachusetts, Harvard Business School Press, 1993), pp. 35-43.
4. Ibid, p. 220.
5. Ibid, pp. 220-221.
6. Womack, James P., Jones, Daniel T., and Roos, Daniel, *The Machine That Changed the World*, (New York, New York, Rawson Associates, 1990), pp. 21-47.
7. Charles H. Fine, *Clockspeed: Winning Industry Control in the Age of Temporary Advantage* (Reading, Massachusetts, Perseus Books, 1998), pp. 3-11.
8. Pine, *Mass Customization*, p. 171.
9. Shoji Shiba, Alan Graham, and David Walden, *A New American TQM: Four Practical Revolutions in Management* (Portland, Oregon, Productivity Press, 1993), p. 69.
10. Pine, *Mass Customization*, p. 196.
11. Ibid, p. 198.
12. Ibid.
13. Ibid, p. 200.
14. Ulrich, Karl T., and Tung, Karen, *Fundamentals of Product Modularity*, Working Paper #3335-91-MSA, Sloan School of Management, MIT, September 1991.
15. Fine, Charles H., and Cohen, Morris, *Architectures in 3D: Concurrent Product, Process, and Supply Chain Development*, working Paper, MIT, Cambridge, MA, 1998.
16. Fujita, K., Sakaguchi, H., and Akagi, S. (1999), *Product Variety Deployment and its Optimization Under Modular Architecture and Module Commonalization*, 1999 ASME Design Engineering Technical Conferences, Las Vegas, NV, DFM-8923.

17. Meyer, M.H., and Lehnerd, A.P. (1997), *The Power of Product Platforms*, New York, The Free Press.
18. Henderson, R.M., and Clark, K.B. (1990), *Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms*, Administrative Science Quarterly 35.
19. Sanderson, S., and Uzumeri, M. (1995), *Managing Product Families: The Case of the Sony Walkman*, Research Policy 24.
20. Data from Air Transport Authority, *Air Transport Association Facts and Figures*, 1994.
21. Boeing 1998 Annual Report.
22. Gerald I. Hartman, Challenging a Sequential Design Process, Master's thesis, p. 18.
23. Ian P. Lawee, Reducing Development Cycle Time for Aircraft Electrical Wiring Systems, (MIT, LFM thesis, 1995), p. 25-27.
24. Ibid
25. Adopted from WIRC industrial engineering office drawing of WIRC Shop Floor Layout.
26. Lawee, 1995, pp. 25-27.
27. Provided by the WIRC engineering leadership team.
28. Sample CER Feedback form, prepared by Garth B. Windley.
29. Ibid.
30. Estimated by representatives from WIRC industrial engineering and finance.
31. Jack Welch, CEO of General Electric, quoted from various speeches.